Superdense and normal early-type galaxies at $1 < z < 2$

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Abstract. We combined proprietary and archival HST observations to collect a sample of 62 early-type galaxies (ETGs) at $0.9 < z < 2$ with spectroscopic confirmation of their redshift and spectral type. The whole sample is covered by ACS or NICMOS observations and partially by Spitzer and AKARI observations. We derived morphological parameters by fitting their HST light profiles and physical parameters by fitting their spectral energy distributions. The study of the size-mass and the size-luminosity relations of these early-types shows that a large fraction of them ($\sim$ 50%) follows the local relations. These 'normal' ETGs are not smaller than local counterparts with comparable mass. The remaining half of the sample is composed of compact ETGs with sizes (densities) 2.5-3 (15-30) times smaller (higher) than local counterparts and, most importantly, than the other normal ETGs at the same redshift and with the same stellar mass. This suggests that normal and superdense ETGs at $z \sim 2$ come from different histories of mass assembly.

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INTRODUCTION

The presence of early-type galaxies (ETGs) at $z > 1$ apparently more compact, hence denser, than local ETGs of comparable mass has caught the attention of many research works in the last 3-4 years. Such compact ETGs, often called superdense, are characterized by effective radii on average ~ 3 times smaller than the mean effective radius of the local ETGs. Among the first to point out the smaller radii of high-z ETGs are [1] who found that 7 ETGs seen in the Hubble Ultra Deep Field (HUDF) at $z > 1.4$ fall out the local Kormendy relation (KR) even taking into account the luminosity evolution. Subsequent studies of small samples of $z > 1$ ETGs based on optical observations or on seeing limited ground-based observations reached similar results [2], [3] and the first deep HST-NICMOS high-resolution (0.075 arcsec/pix) observations in the near-IR of a sample of $z > 1$ ETGs confirmed their compactness [4]. The many independent confirmations of the small effective radius of high-z ETGs which followed [5], [6], [7], [8] point toward the need of an evolution of the effective radius R_e of ETGs from their redshift to $z = 0$. Recently, [9] studying a sample of ~ 30 ETGs at $1.2 < z < 1.8$ found that a large fraction of them are actually not more compact than local ETGs and that those more compact tend to be older. Here we present the results based on a sample twice the one studied by [9] extending the analysis over a wider range of stellar masses and redshift.

THE DATA SET

The sample of ETGs we constructed is composed of 62 ETGs at $0.9 < z_{spec} < 2$ and magnitudes $17 < K_{Vega} < 20.5$, 28 of which covered by HST-NICMOS observations (NICMOS sample hereafter) in the F160W filter ($\lambda \sim 1.6\ \mu$m) and 34 by HST-ACS observations (ACS sample hereafter). The NICMOS sample[1] was analysed by [9] to which we refer for a detailed description of the data and of the various surveys from which they have been extracted. The ACS sample falls on to the southern field of the Great Observatories Origins Deep Survey (GOODS-South v2; [10]). The photometry, composed of 14 photometric bands (from UV to mid-IR), comes from the GOODS-MUSIC multiwavelength catalog [11] while spectroscopic information come from the ESO-VLT spectroscopic survey of the GOODS-South field ([12] and references therein).

SUPERDENSE AND NORMAL EARLY-TYPES AT $1 < z < 2$

We derived the morphological (effective radius) and the physical parameters (stellar mass) to study the size-mass and the size-luminosity relations for our sample of ETGs. The effective radius r_e [arcsec] was derived by fitting a Sérsic profile to the observed galaxy profile in the HST NICMOS-F160W and ACS-F850LP images using `Galfit` software (v. 2.0.3). Stellar masses $\mathscr{M}_*$ were derived by fitting the stellar population synthesis models of Charlot & Bruzual (hereafter CB08, in preparation) to the observed SED at the spectroscopic redshift z_{spec}. We considered the Chabrier initial mass function (IMF), four exponentially declining star formation histories (SFHs) $\tau = [0.1, 0.3, 0.4, 06]$ Gyr and metallicity 0.4 $Z_\odot$, $Z_\odot$ and 2 $Z_\odot$ (see [9] for a detailed description of the morphology and SED fitting). In Fig. 1 the size-mass (SM) relation, that is the relation between the effective radius R$_e$ [kpc] and the stellar mass $\mathscr{M}_*$ [M$_\odot$] of our galaxies is compared with the SM relation found by [14] for the local population of ETGs (solid line). The local SM relation has been scaled by 0.8 to account for the larger stellar masses provided by the Bruzual and Charlot (2003) models with respect to the CB08 models (see [13]). Fig. 1 shows that ∼50% of the sample (29 out of 62 ETGs, filled green triangles) agrees at 1σ with the local SM relation, that is it is composed of ETGs having morphological and physical parameters equal to those of local ETGs (see also [15], [16]). The remaining 33 ETGs of the sample (filled purple circles) diverge more than one sigma from the local SM relation being them more compact than local ones. The way in which our sample has been constructed does not allow us to quantify the real fraction of normal and compact ETGs at $z > 1$. However, it is well known that both imaging and spectroscopic observations are biased toward compact galaxies since they have a higher probability to be detected thank to the higher S/N ratio. Since our sample collects different surveys, it will be biased toward compact ETGs too rather than the opposite. Thus, the actual fraction of normal ETGs at $z > 1$ cannot be lower than $\sim 50\%$, the fraction we observe in our sample and, consequently, the population of high-z ETGs is not dominated by galaxies more compact than the local ones.

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[1] Available at `www.brera.inaf.it/utenti/saracco/32sample.html`

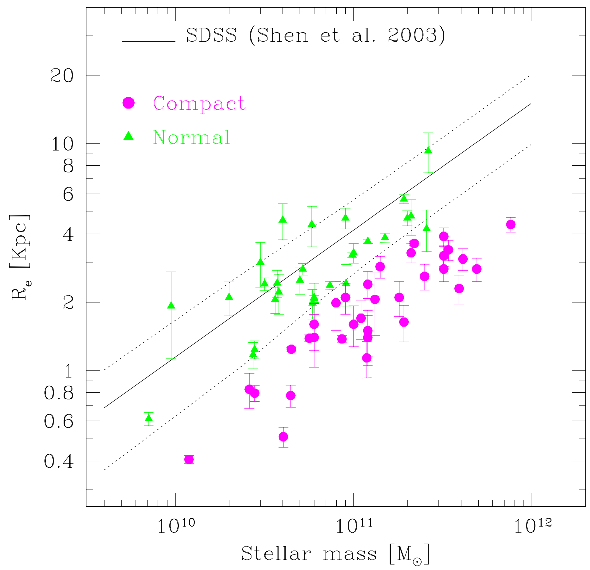

FIGURE 1. Effective radius R_e versus stellar mass for our sample of ETGs at $0.9 < z < 2$. The local Size-Mass relation (solid line) found by [14] and the relevant scatter (dotted lines) are also shown. Circles mark compact ETGs having R_e 1σ smaller than the local relation; triangles mark normal ETGs.

As to the 33 compact ETGs, their effective radius is on average 2.5-3 times smaller than the mean effective radius of local early-types, that is their stellar mass density is on average 15-30 times higher. This offset with respect to the local relation is constant over the whole mass range spanned by our sample (from 10^{10} $M_\odot$ to 10^{12} $M_\odot$), that is no evidence of a dependence of the compactness on galaxy mass is found. Apart from this, we believe that the most significant result is not the possible higher compactness shown by compact ETGs with respect to the local population, but rather their higher compactness with respect to the normal ETGs at the same redshift. Indeed, Fig. 1 shows clearly that at $z \sim 1.5$ and beyond, when the Universe was only 3-4 Gyr old, ETGs fully similar to local ones coexisted with other ETGs 15-30 times denser in spite of the same redshift and the same stellar mass of all of them. This result is not dependent on the scaling relation considered. Indeed, considering the size-luminosity (SL) relation we obtain an analogous result. This is shown in Fig. 2 where the SL relation, the relation between R_e and the absolute magnitude M_R in the R-band of our galaxies, is compared with the local SL relation [14]. The absolute magnitude M_R of our galaxies is the one at the redshift of the galaxies (left-hand panel). The offset with respect to the local relation reflects the evolution which ETGs undergo from their redshift to $z = 0$. In the right-hand panel of Fig. 2 it is shown how the 62 ETGs of our sample would be displaced at $z = 0$ in the [M_R,R_e] plane in case of pure luminosity evolution. The agreement between this result and the one derived by the SM relation (Fig. 1) is remarkable: with very few exceptions, normal ETGs fall within one sigma from the local relation and compact ETGs diverge more than one sigma from the relation. This result naturally leads us to conclude that compact and normal ETGs result from two different assembly and

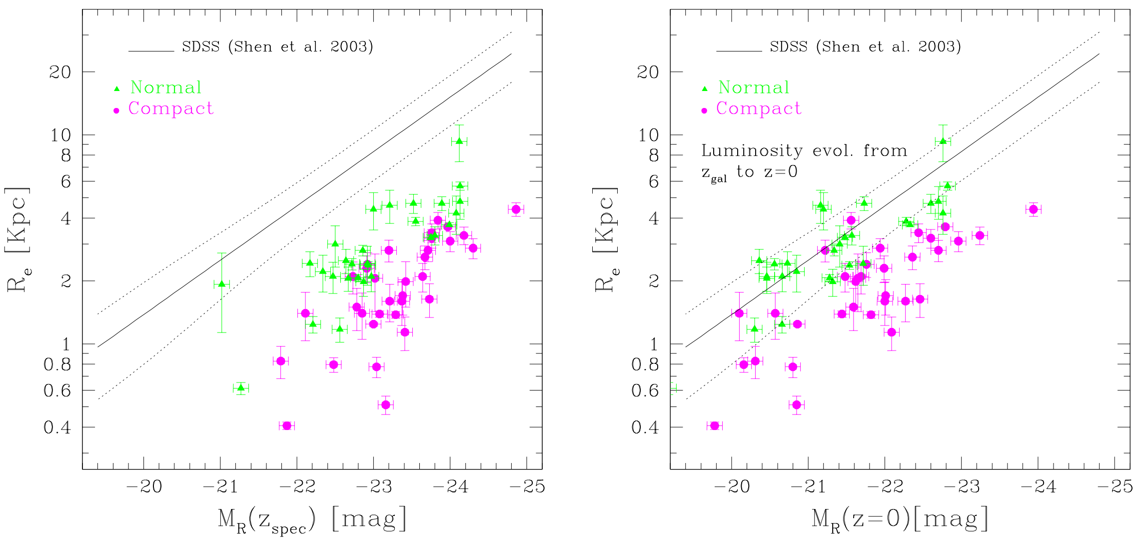

FIGURE 2. Left-hand panel: SL relation for our sample of ETGs at $0.9 < z < 2$ compared with the local relation. Symbols are as in Fig. 1. Right-hand panel: SL relation in case of pure luminosity evolution. It is shown how the 62 ETGs of our sample would be displaced at $z = 0$ in case of pure luminosity evolution

evolutionary paths covered at $z >> 2$.

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